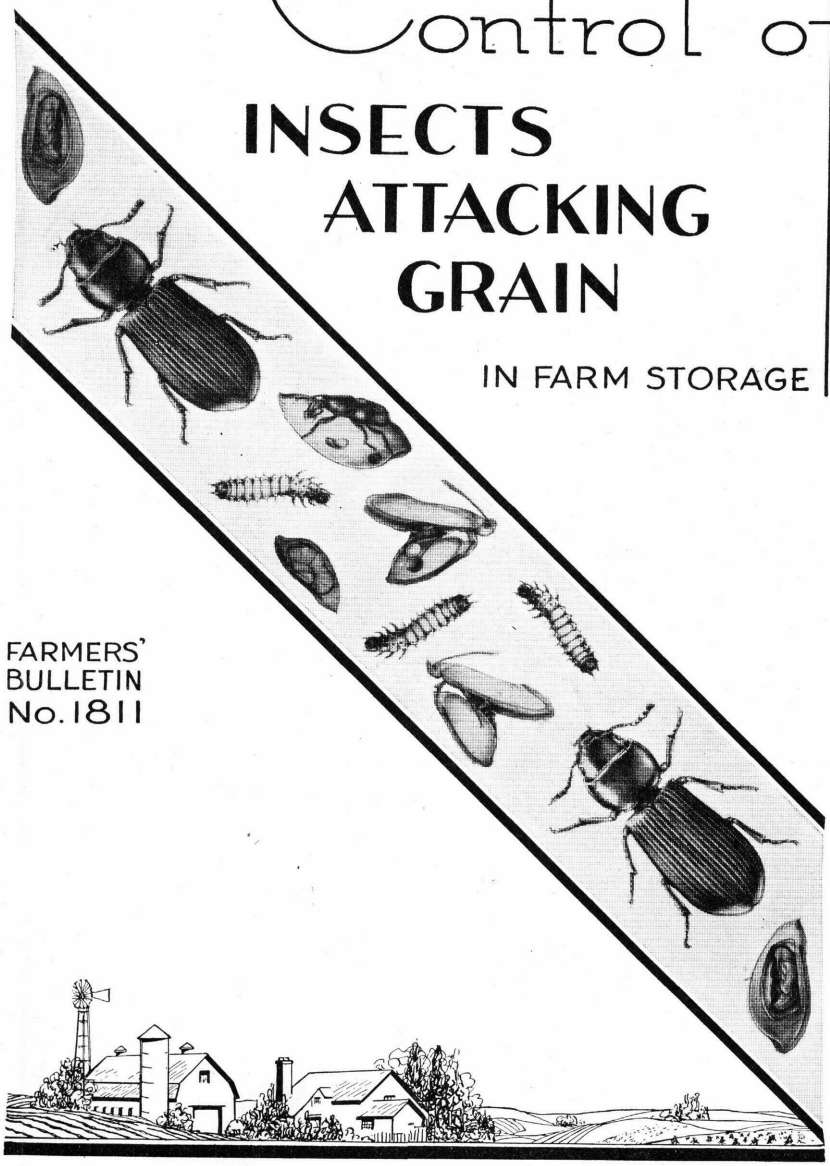
UNITED STATES DEPARTMENT OF AGRICULTURE

Control of INSECTS ATTACKING GRAIN IN FARM STORAGE



FARMERS' BULLETIN No. 1811

IN MANY PARTS of the United States grain cannot safely be stored unless it is properly protected from insects. This protection is so difficult in the South that farm storage of grain is not recommended there.

The insects most injurious to grain in storage are the Angoumois grain moth, the Indian meal moth, the rice weevil, the lesser grain borer, the cadelle, and the several "bran bugs." These are described briefly, and conditions that favor their multiplication are pointed out.

The most common causes of insect damage to grain are failure to clean out the bins thoroughly before they are filled with the new grain and storing near the bins quantities of feed that have been purchased from mills where insects are abundant.

Grain that has become infested with any species of insect should be fumigated as soon as possible. This bulletin tells about the different kinds of fumigants, their cost, and how they should be used.

Washington, D. C.

Issued October 1938
Revised January 1942

CONTROL OF INSECTS ATTACKING GRAIN IN FARM STORAGE

By R. T. COTTON, *senior entomologist, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine*

Contents

A LARGE GROUP OF INSECTS feed and breed in stored grain. In many cases the infestations originate on the farms where the grain is produced and stored until it is marketed or utilized for feeding purposes. To avoid serious insect damage to grain while it is stored on the farm, it is essential to employ methods of handling and storage that will prevent infestation, or treatment that will suppress infestations before they reach serious proportions.

THE MORE IMPORTANT INSECTS THAT ATTACK STORED GRAIN

Of the many kinds of insects found associated with stored grain only a few ordinarily cause serious damage. A brief account of the more important of these insects is given in this bulletin.

THE ANGOUMOIS GRAIN MOTH

The Angoumois grain moth (*Sitotroga cerealella* (Oliv.)) is the moth most commonly found in infested grain. In the South and extending up into the southern portion of the commercial corn area of the Central States it flies from the farm buildings, where it has been breeding in stored grain, to the fields of ripening corn. In years when it is abundant considerable infestation of the new crop occurs in the field. Corn usually is stored on the ear for the first season after harvest, and, except where winter temperatures are severe, infestations that originated in the field survive the winter and begin to spread with

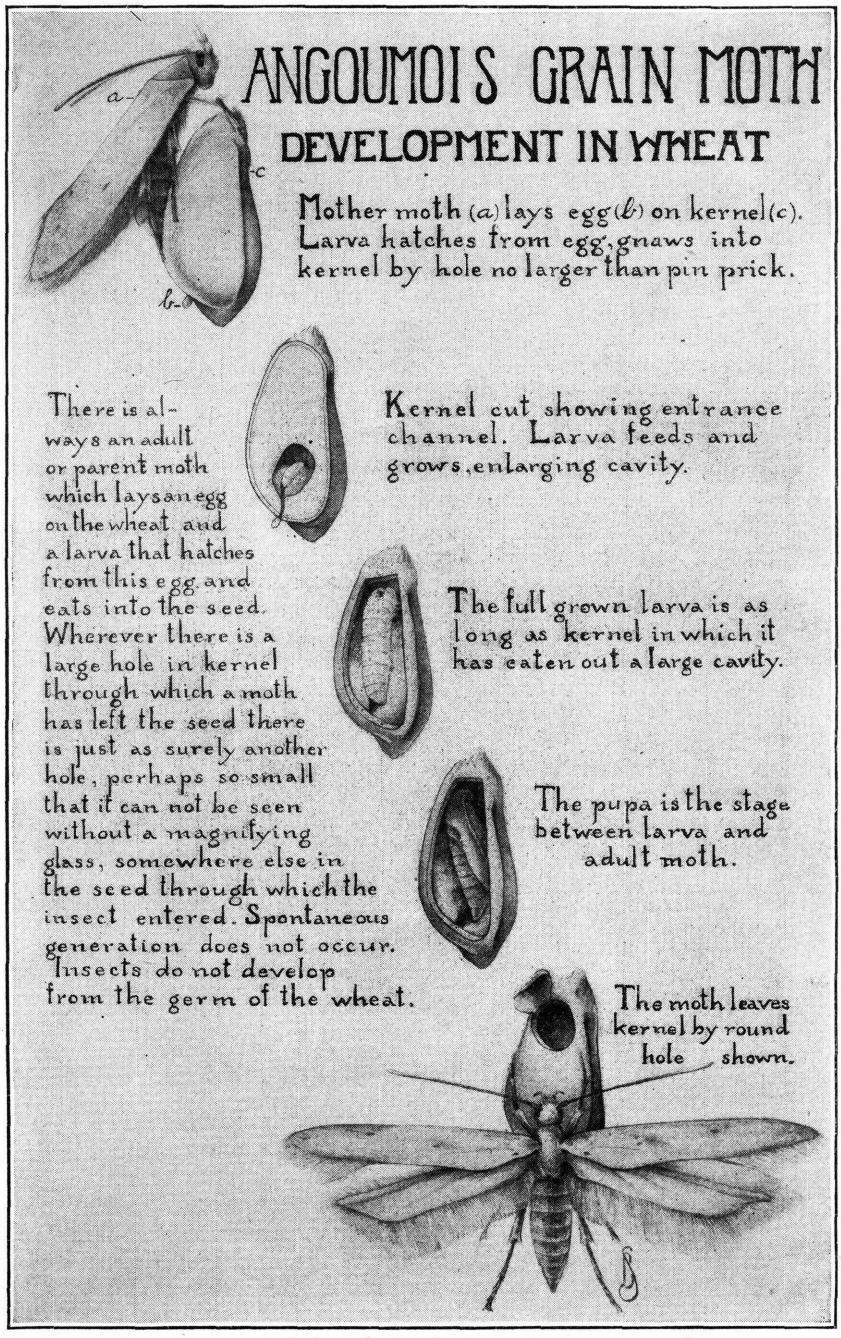


FIGURE 1.—Life cycle of Angoumois grain moth on wheat.

the arrival of warm weather. During spring and early summer, if the corn is not shelled, the moths can disperse all through the crib and cause an ever increasing degree of infestation. Further damage can be largely prevented by shelling and storing the corn in tight bins where only the surface grain remains exposed to infestation.

In the part of the Eastern and Central States where soft red winter wheat is grown, moths from stored grain in farm buildings or from waste grain in and around straw stacks lay their eggs on the heads of the growing wheat in the field. Although this initial infestation in the field is low, the insect can increase rapidly. In the Eastern States, where threshing often is delayed, the infestation may develop to enormous proportions before the grain can be safely stored. In some years infestation of wheat in Maryland has been observed to reach as high as 90 percent of the kernels by the end of September when threshing was delayed that long. Before the wheat is threshed the moths can easily make their way from one wheat head to another, with the result that infestation is unimpeded; but after the grain is threshed and stored it becomes impossible for the soft-bodied moths to make their way below the surface of the grain, and infestation is restricted to the surface layer. Damage to wheat by the Angoumois grain moth can be largely prevented by the prompt threshing of the crop.

Proper fumigation of corn or wheat after it has been placed in tight bins will prevent further damage from infestation that is already present in it.

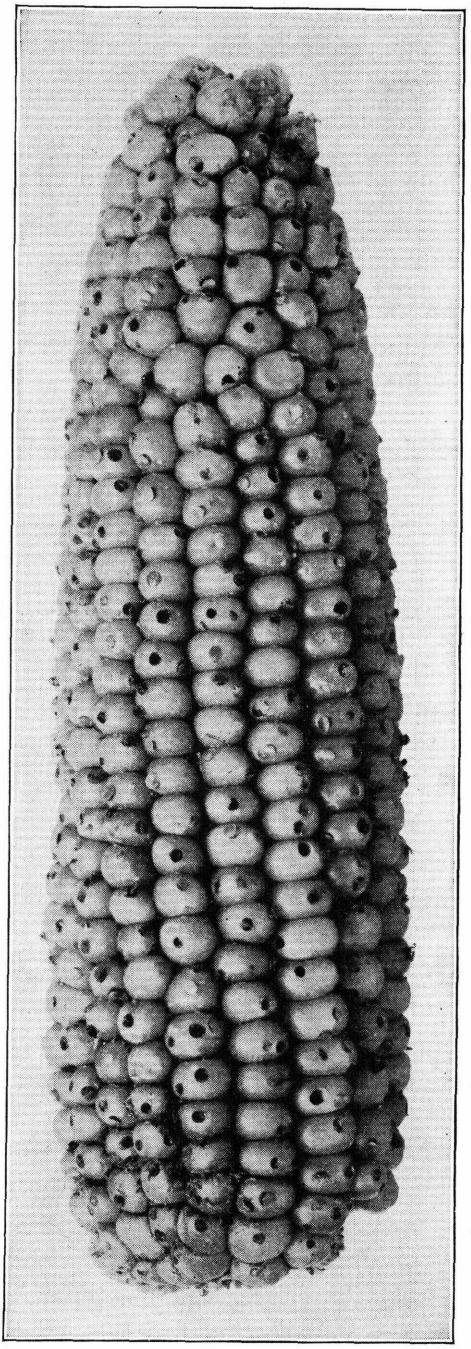


FIGURE 2.—Ear of corn showing emergence holes of the Angoumois grain moth.

Each female of the Angoumois grain moth lays on an average about 40 eggs, although as many as 389 eggs have been recorded from 1 moth. The eggs, which are laid on or near the grain, hatch into minute white larvae, or caterpillars, that bore into the kernels of grain and begin feeding on the contents. When full-grown, each larva eats out a channel almost to the outside of the seed but leaves a thin layer of the seed coat intact. It then changes to a reddish-brown pupa, and later the adult or moth emerges, pushing aside the thin section of seed coat that covers the exit from the channel. The development from egg to adult may be completed in 5 weeks. Figure 1 shows the successive stages in the development of this insect in a kernel of wheat from the time the egg is laid until the moth appears. Typical injury to the kernels of an ear of corn is shown in figure 2.

THE INDIAN-MEAL MOTH

The Indian-meal moth (*Plodia interpunctella* (Hbn.)) (fig. 3) is another moth that is exceedingly troublesome, although it does not cause as much damage as the Angoumois grain moth. It breeds freely in grain and feeds of all kinds around the farm and flies to bins of shelled corn or other grains where the larvae, or "worms," may completely web over the surface by matting the surface grains together with silken threads. This insect is primarily a surface feeder. The larvae are usually found in the top 12 or 16 inches of small grain, but in bins of corn they are sometimes found at much greater depths. When the larvae are ready to change to moths they crawl away in search of a place to transform, and it is not unusual to see the sides of bins covered with the crawling worms. Fortunately this insect is attacked by a hymenopterous parasite, *Microbracon hebetor* Say, that often becomes exceedingly abundant during outbreaks of the moth, and in many cases effectively controls the infestation, particularly if the surface of the infested bin is kept raked over to allow the parasites to reach the worms.

The Indian-meal moth is a handsomely marked moth with a wing expanse of about three-fourths of an inch. The wings are reddish brown with a coppery luster on the outer two-thirds and whitish gray on the inner or body end. The female moth lays on an average about 200 eggs, placing them singly or in groups on the foodstuff. The caterpillars that hatch from the eggs are dirty white, with sometimes a greenish or pinkish tint. When fully grown they are about half an inch long. In summer the period from egg to adult occupies about 4 weeks.

THE RICE WEEVIL

The rice or black weevil (*Sitophilus oryza* (L.)) is the most destructive insect pest of stored grain. It is a small, dark-reddish-brown beetle, with the head prolonged into a long, slender snout, at the end of which are a pair of stout mandibles, or jaws. It is further characterized by being marked on the back with four light-reddish or yellowish spots. The adult weevil, the full-grown larva or grub, and the pupa are shown in figure 4. Both adults and larvae feed voraciously on a great variety of grains.

In the South, the adults fly from granaries or other places containing grain to the fields of corn and wheat and originate the infestations that prove so disastrous after the grain has been harvested. In the more northern grain-growing regions this weevil is prevalent in accumula-

tions of old grain in and around granaries and barns and infests the new grain when it is stored in farm bins. It is not very resistant to cold, and in the North Central States infestations in farm-stored grain are usually killed out each winter except in protected situations.

The adult weevil lives on an average from 4 to 5 months, each female

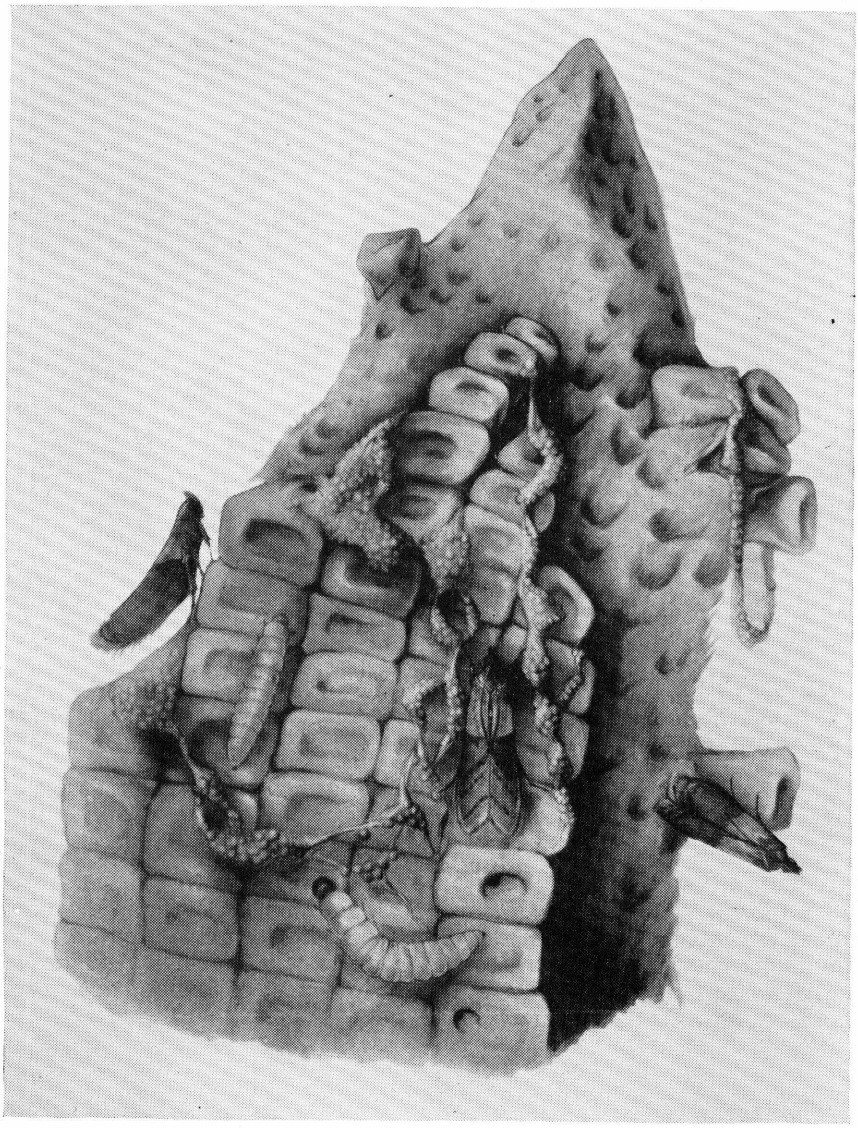


FIGURE 3.—Adults and larvae of the Indian-meal moth on ear of corn.

laying between 300 and 400 eggs during this period. Before laying an egg, the female bores a small hole in the grain with her mandibles. She then turns about and lays in it an egg, which she covers with a gelatinous fluid that seals the hole. The small, white, fleshy, and legless grub that hatches from the egg burrows about inside the

kernel and never leaves it until fully grown. Then it transforms to a pupa and then to an adult weevil, which bores its way out of the grain. During warm weather the egg, larval, and pupal stages may be passed in as few as 26 days. The only way to protect grain in the South from damage by the rice weevil (fig. 5) is to fumigate the grain in tight bins immediately after harvest.

A closely allied species, the granary weevil (*Sitophilus granaria* (L.)) (fig. 6) has no wings and cannot infest grain in the field. It is established on many farms in the North Central States, breeding from year to year in supplies of grain around the farm buildings.

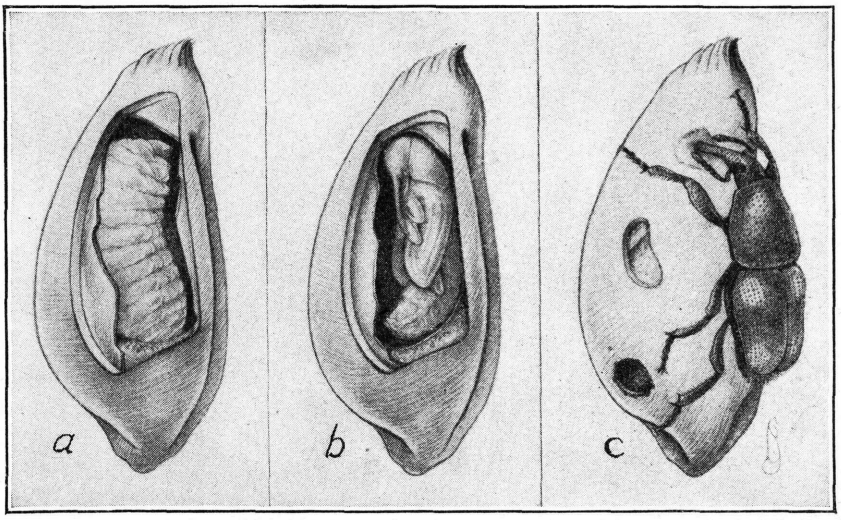


FIGURE 4.—Life stages of the rice weevil, or black weevil, in wheat: *a*, Well-grown larva; *b*, pupa; *c*, adult feeding upon kernel. Note in *c* the hole in lower portion of kernel made by the adult on leaving the seed and at two points higher up shallow holes made by the adult in feeding upon the seed after emergence.

It is more resistant to cold than the rice weevil and is more likely to survive the winter in farm-stored grain.

THE LESSER GRAIN BORER

The lesser grain borer (*Rhizopertha dominica* (F.)) (fig. 7), which causes so much damage to grain stored in terminal elevators, is found occasionally in farm-stored grain as far North as Oklahoma and Kansas. It is not yet (1941) a serious pest of farm-stored grain in the main grain-growing regions.

THE CADELLE

The larvae of the cadelle (*Tenebroides mauritanicus* (L.)) have the unfortunate habit of burrowing in enormous numbers into the woodwork of bins, where they may remain for long periods, only to come out when fresh grain is placed in the bin. Many seemingly clean and empty bins may thus actually harbor thousands of hungry insects, and it is not an uncommon sight to see newly threshed grain literally swarming with insects a few weeks after it had been placed in in-

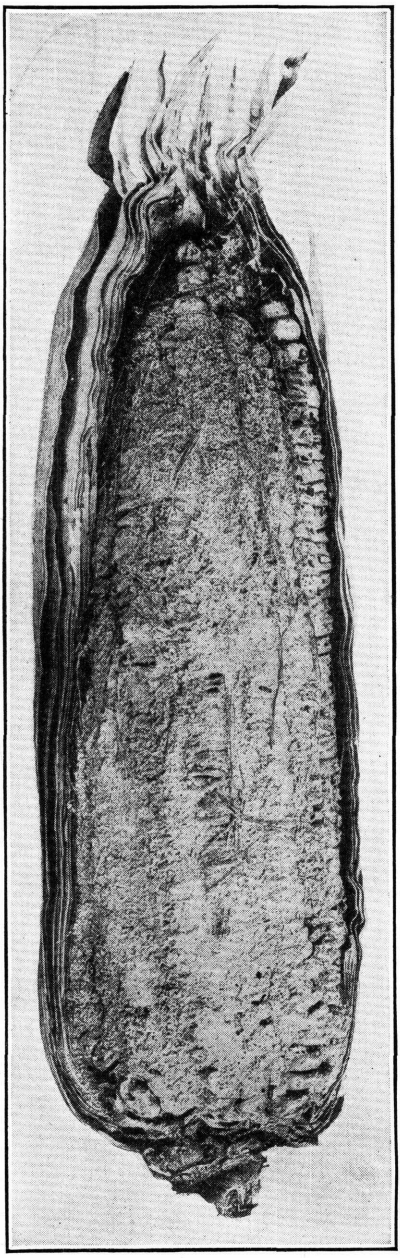


FIGURE 5.—In the South corn is infested by the rice weevil in the field, and unless the corn is fumigated and stored in insect-tight cribs it is soon reduced to the state of the ear shown above.

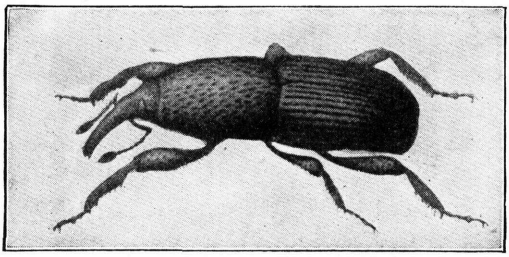


FIGURE 6.—Adult of the granary weevil.

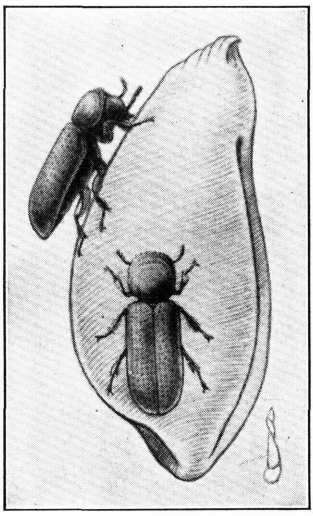


FIGURE 7.—Adults of the lesser grain borer on grain of wheat.

416144°—42——2

fested wooden bins. Owing to this habit of the larvae, this insect is one of the commonest pests of grain stored on the farm in all parts

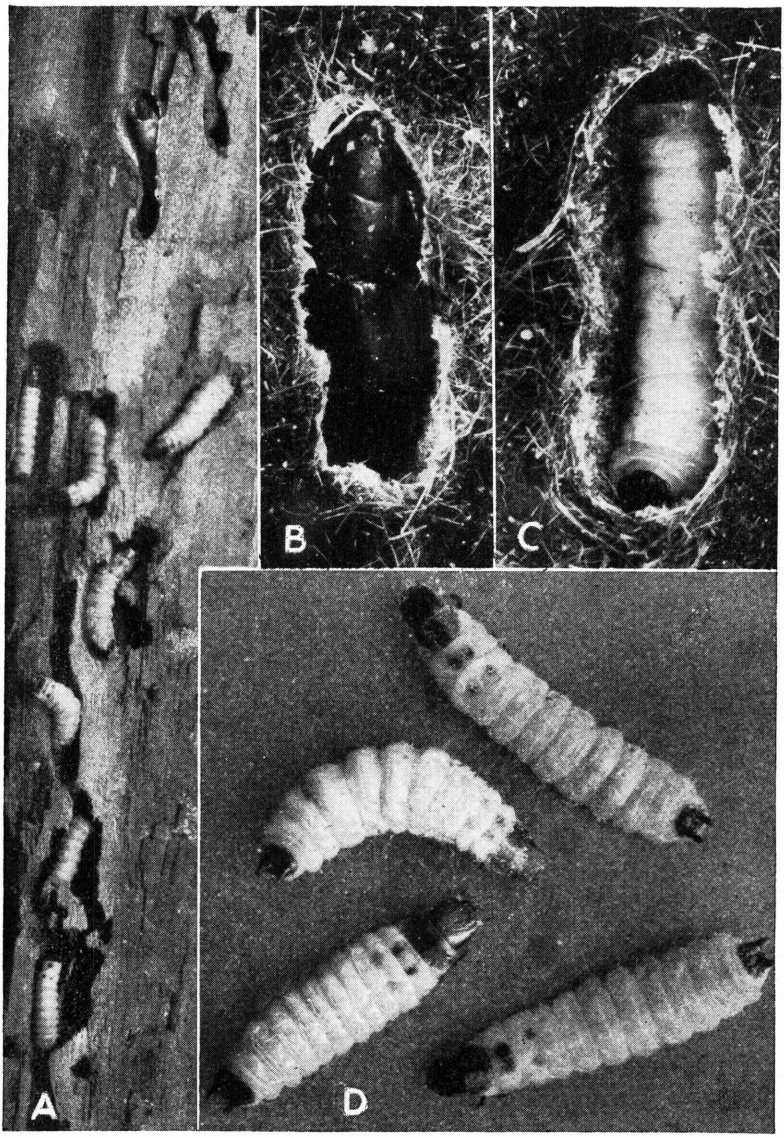


FIGURE 8.—Hibernation of the cadelle: *A*, Sectioned board from granary used for wheat storage, showing numerous larvae of the cadelle using board for a place in which to pupate: *D*, cadelle larvae about to pupate; *C*, cadelle larva hibernating in pupal chamber; *B*, same as *C*, only several months later, after larva has transformed to adult.

of the country. The burrows, which are well illustrated in figure 8, also afford hiding places for many other grain-infesting insects.

The adult cadelle (fig. 9) is an elongate, oblong, and flattened, black beetle about one-third of an inch long. It is one of the longest-

lived of the insects that attack stored grain. Many of the adults live for more than a year and some for nearly 2 years. The females lay about 1,000 eggs each, which hatch in from 7 to 10 days into fleshy, chalky-white larvae with black heads and 2 horny black points at the rear end of their bodies. When fully grown the larva is about three-fourths of an inch long. The developmental period from egg to adult may be completed in 70 days under favorable conditions but frequently takes much longer.

The best insurance against this insect is to clean empty bins thoroughly and fumigate newly stored grain within a few days after it has been stored.

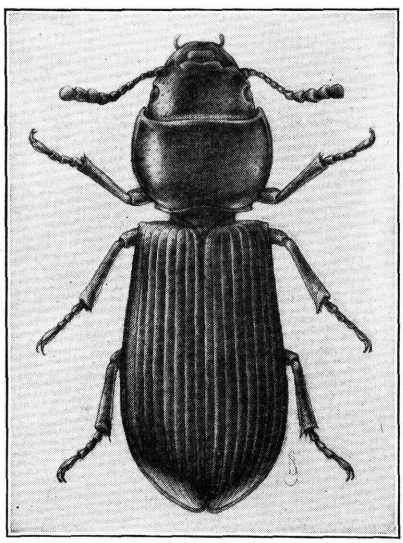


FIGURE 9.—The cadelle, one of the most common pests in farm-stored grain. About 8 times natural size.

"BRAN BUGS" AND FUNGUS BEETLES

A number of species of beetles that are not primary grain pests but that feed in broken grain, moldy grain, grain dust, or grain damaged by the true grain beetles are often of considerable importance not only because of the damage caused by their feeding but also because the activities of large numbers of these insects may cause heating and an increase in the moisture content of the grain with consequent spoilage of portions of it. These insects, some of which are called "bran bugs" and others fungus beetles, are particularly troublesome in shelled corn stored in the North Central States. They may be even more so than the primary stored-grain insects that do not survive so well the winters of this region.

The different species of "bran bugs" and "fungus beetles" range in length from one-sixteenth to one-seventh inch and are usually either brown or black. The confused flour beetle (*Tribolium confusum* Jacq.-Duv.) (fig. 10) and the red flour beetle (*T. castaneum* (Hbst.)), which are included in this group, are the worst pests of flour, and their presence in grain constitutes the chief source of infestation in flour mills. The saw-toothed grain beetle (*Oryzaephilus surinamensis* (L.)) (fig. 11) and the flat grain beetle (*Laemophloeus minutus* Oliv.) (fig. 12) are other typical examples of bran bugs. The saw-toothed grain beetle is exceedingly abundant in the commercial corn area in bins of shelled corn that contain a large percentage of broken kernels.

The hairy fungus beetle (*Typhaea stercorea* (L.)) (fig. 13) and the foreign grain beetle (*Ahasverus advena* (Waltl)) (fig. 14) are also extremely abundant in bins of shelled corn in the commercial corn area, particularly if the surface layer has a high moisture content or shows signs of molding. Two other species that are attracted to grain having high moisture content and are sometimes found infesting shelled corn in this region are *Cynaeus angustus* (Lec.), a dark-brown to black beetle about one-fifth inch long (fig. 15), and *Platydema rufi-*

corne (Sturm), which is velvety-black and about three-sixteenths inch in length (fig. 16). They are but little known as pests of stored grain and probably thrive only in grain of high moisture content.

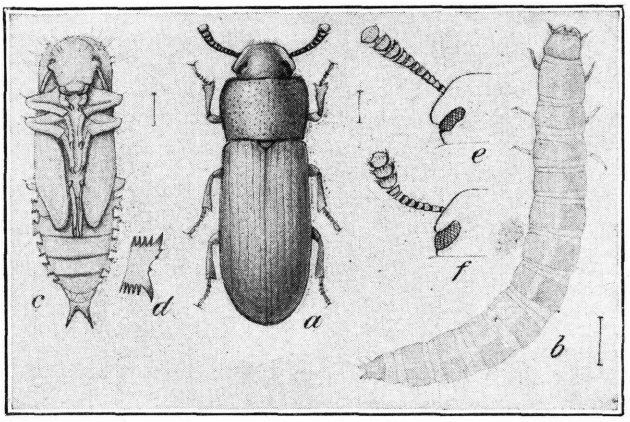


FIGURE 10.—The confused flour beetle, one of the most important of the so-called bran bugs. It is about one-sixth of an inch long. *a*, Beetle; *b*, larva; *c*, pupa; *d*, lateral lobe of abdomen of pupa; *e*, head of beetle, showing antenna; *f*, same of the red flour beetle.

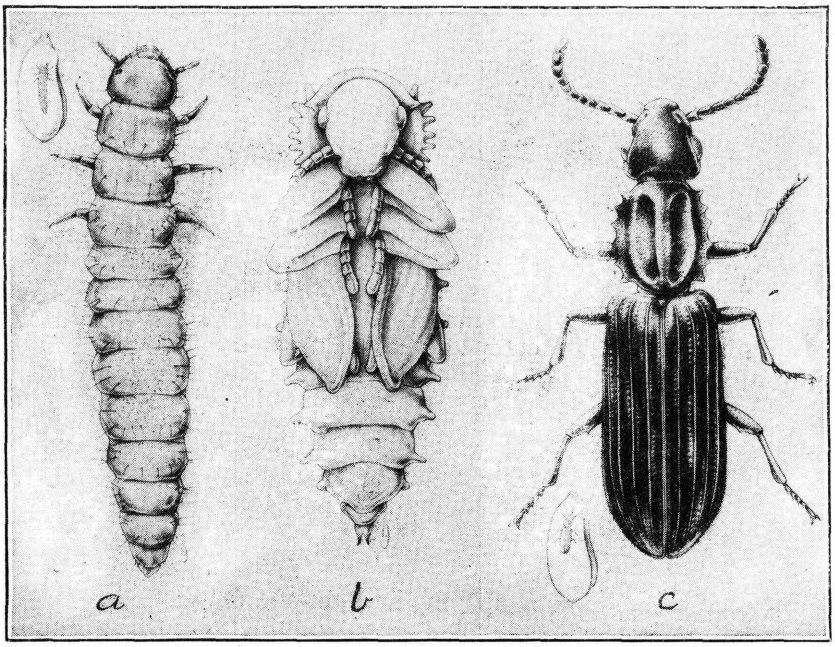


FIGURE 11.—The saw-toothed grain beetle, a frequent inhabitant of stored grain: *a*, Well-grown larva; *b*, pupa; *c*, adult beetle.

The practice of storing millfeeds, chicken feed, and screenings in or near the granary and failing to clean out accumulations of infested grain from bins is largely responsible for infestation of grain by bran

bugs. Feeds and screenings are usually infested with insects of this type, and the habit of these insects of migrating when they become abundant, or when they are disturbed. insures the infestation of any nearby grain or cereal product.

Storing grain in bins well removed from all millfeeds, chicken feed, or other cereal products, and cleaning out bins before the storage of grain will do much to prevent infestation by bran bugs.

For a more detailed description of the life histories and habits of the insect pests of stored grain the reader is referred to Farmers' Bulletin 1260, entitled "Stored-Grain Pests," which may be obtained from the United States Department of Agriculture.

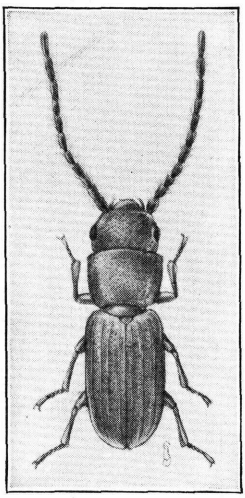


FIGURE 12.—The flat grain beetle, the smallest bran bug found in stored grain, and often more numerous than any other species. Not more than one-sixteenth of an inch long.

INFESTATION IN THE FIELD

In many grain regions infestation starts in the field before the crops are harvested. This is particularly true in the South, where many insects survive the mild winters and where the growing grain is attacked as soon as it begins to ripen. Many of the insects involved are strong fliers and may travel for miles from sources of infestation around farm buildings. Heavy flights of the rice weevil from infested corn cribs occur each year in the Southern States, and it is not unusual to find cornfields in Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas with almost every ear infested in the field before harvest. In addition to the rice weevil, other insects that are particularly abundant in the cornfields of the South, attacking the ripening grain, are the Angoumois grain moth, the pink corn worm (*Pyroderces rileyi* (Wals.)), the square-necked grain beetle (*Cathartus quadricollis* (Guer.)), the foreign grain beetle (*Ahasverus advena*), and flour beetles of the genera *Tribolium* and *Gnathocerus*.

Farther North few species are able to survive the winter in the field, although a certain number overwinter in barns and granaries where they are protected from the cold. The congregation of large numbers of insects in stored grain or milled cereal products causes heating to occur, so that insects in these "hot spots" are not only protected from the cold but continue actively breeding throughout the winter. Some of these overwintered insects later fly to the nearby fields and lay their eggs in or near the ripening grain. For the most part the resulting infestation is not serious unless conditions favorable to the insect allow a rapid increase in numbers after the grain has been placed in storage.

In Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and North Carolina, where soft red winter wheat is grown, field infestation of wheat by the Angoumois grain moth occurs each year. Outbreaks of this insect appear to depend on particularly favorable weather conditions. A mild winter favors the survival of large numbers of the hibernating insects. If this is followed by hot weather

from June to October, the infestation originating in the field is likely to increase to outbreak proportions unless grain is promptly threshed after harvest.

In the southern portion of the commercial corn area field infestation

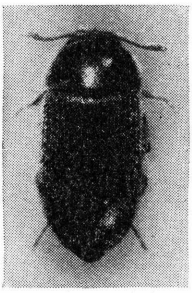


FIGURE 13.—Adult of the hairy fungus beetle. 12 times natural size.

FIGURE 14.—Adult of the foreign grain beetle. 20 times natural size.

of corn by the Angoumois grain moth is common and after a succession of mild winters is likely to reach serious proportions.

Severe winters serve greatly to reduce the numbers of hibernating insects, and the occurrence of an outbreak of the Angoumois grain moth after a hard winter is extremely unlikely.

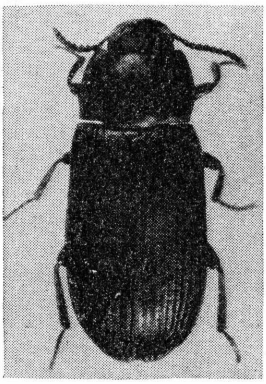


FIGURE 15.—Adult of the tenebrionid beetle *Cynaeus angustus* (Lec.). 9 times natural size.

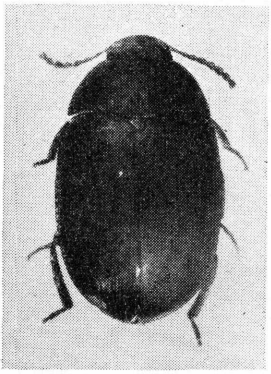


FIGURE 16.—Adult of *Platydema ruficorne* (Sturm). 8 times natural size.

OTHER SOURCES OF INFESTATION

In addition to field infestation, which may or may not be of importance, depending upon the region or the season, several other sources of infestation of stored grain are of considerable concern in all grain-growing areas.

In all regions it is customary to store grain year after year in the same bins. Cracks and crevices in the bins become filled with dust

and broken grain, and afford hiding places for many insects. Insects such as the cadelle burrow into the sides or floors of wooden bins to rest and pupate, and later emerge in great numbers. Many bins are constructed with linings that do not fit tightly or do not extend to the top of the bin. Any space back of this lining forms a pocket that invariably becomes filled with grain that is difficult to remove and serves as a perpetual breeding place for insects. In the rush of harvest the cleaning out of bins is frequently slighted or omitted altogether; hence insects present in accumulations of old grain and in cracks, crevices, and burrows quickly contaminate the entire new crop.

The storage of bran, shorts, and other milled feeds in or near the granary is another serious source of infestation for stored grains.

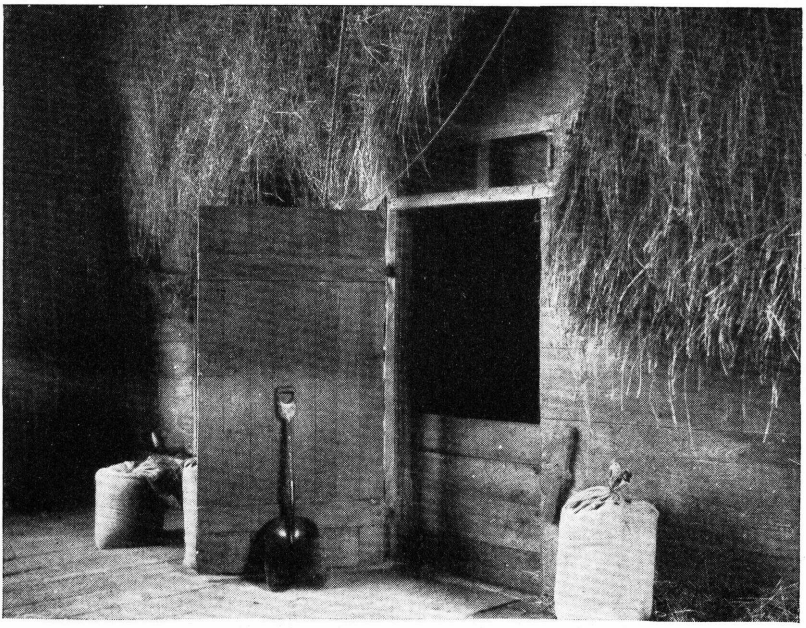


FIGURE 17.—A typical barn granary. Note bags of feed.

These milled products frequently harbor many species of flour beetles, grain beetles, or "bran bugs," which sooner or later migrate to the bins of grain. Barns contain many products in which insects breed, and the practice of locating granaries in corners of these buildings frequently results in the infestation of grain stored there. Illustrations of such conditions are shown in figures 17 and 18.

REGIONAL ABUNDANCE

Many of the insect pests of stored grain and milled cereals are of tropical or subtropical origin. They thrive well in warm, humid climates, but not so well in either dry or cold environments. These factors, therefore, largely determine their relative abundance and destructiveness in the various grain-growing regions of the United States.

In the extreme South, especially where rainfall is abundant and the climate is warm and humid, the storage of grain and cereal products is extremely hazardous. Insects breed with little interruption the year around, and extreme care is required to prevent heavy losses from their feeding.

In the Eastern and Central States the insect pests of stored grain are invariably troublesome, although less difficulty is experienced in preventing loss from their attack than in the South. The colder winters have a limiting effect on their abundance that is not encountered in the South. Smaller numbers of grain insects are found in the

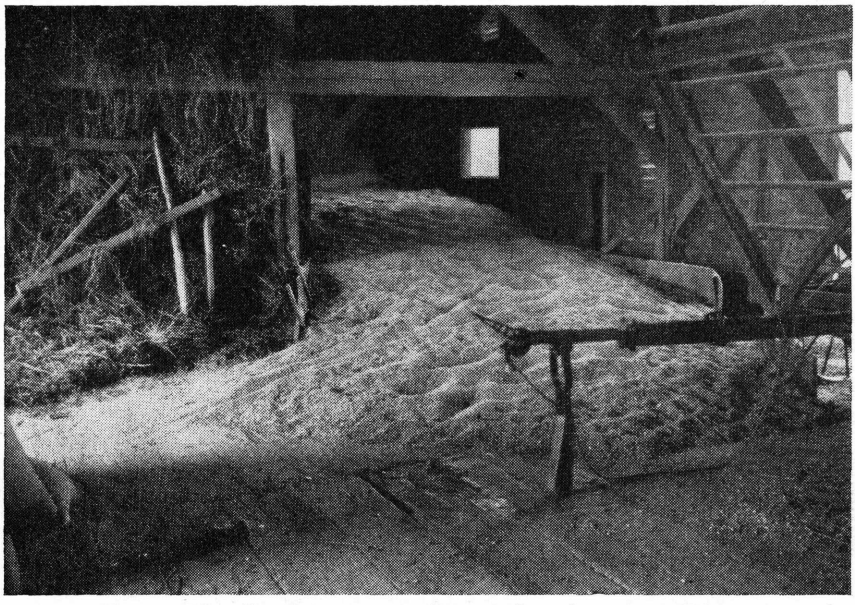


FIGURE 18.—Barn storage of wheat under adverse conditions.

white wheat area of California, although there the lack of moisture rather than low winter temperatures is the limiting factor.

Grain in the Central Great Plains area normally has a low moisture content when harvested and in average years is not seriously injured by storage pests. In certain seasons, however, when rainfall is abundant at time of harvest, the grain is likely to be high in moisture content, and extensive damage to farm-stored grain from insect attack may occur.

In the spring wheat area of the Northern States, and in the Northern portion of the hard and soft winter wheat areas, severe winters serve to limit the abundance of insects in stored grain. Corn can be safely stored in open slat cribs, and wheat rarely suffers weevil damage. United States grain-inspection records show that less than 1 percent of the cars of grain arriving on the Minneapolis market grade weevily, even in the worst years, and it is quite likely that much of the infested grain arriving on this market may have come from other regions. Grain in the semiarid white wheat area of the Pacific Northwest is similarly remarkably free from insect infestations, owing to the cold winters and the very low moisture content of the grain grown there.

Since climatic conditions influencing the abundance of the insect pests of stored grain vary in different portions of the country, the hazard to farm-stored grain from insect damage also varies. For purposes of convenience, the country has been divided into four general regions, as shown in figure 19, in each of which the problem of protecting stored grain from insect attack is distinctly different. A brief discussion of the insect problems in each region follows.

GRAIN STORAGE IN REGION 1

Region 1 (fig. 19) comprises for the most part the spring wheat area of the Northern States, the semiarid white wheat area of the

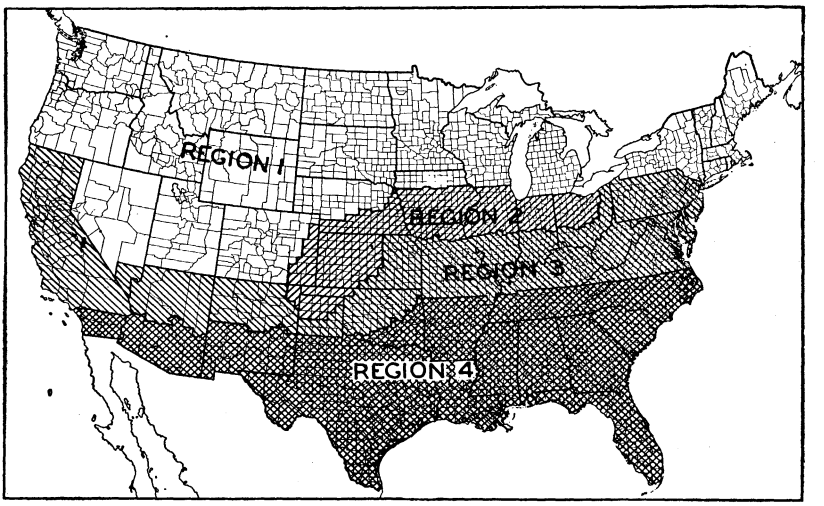


FIGURE 19.—Regional map of the United States, indicating relative hazard to farm-stored grain from insect attack: Region 1, best adapted for safe farm storage for first season. Region 2, insects troublesome in some years—frequent inspection and occasional fumigation necessary. Region 3, insects troublesome every year—frequent inspection and fumigation necessary. Region 4, insect control difficult—special precautions must be taken if grain is stored on the farm in this region.

Pacific Northwest, and the northern portion of the hard and soft winter wheat areas. In these areas wheat can be stored on the farm with greater freedom from insect damage during the first season than in any other section of the country. The chief source of infestation is from insects in accumulations of old grain, in cracks, crevices, and burrows in the woodwork of bins, and from infested millfeed and chicken feed stored on the farm.

Grain-storage structures of all kinds should be thoroughly cleaned, accumulations of old grain removed, and the woodwork sprayed (p. 18) before new grain is stored. Inspection in the fall and subsequent inspections at monthly intervals during the warm weather of the following year are recommended to detect the presence of any insect infestation. Grain found seriously infested should be fumigated without delay.

GRAIN STORAGE IN REGION 2

Region 2 (fig. 19) includes the southern portion of the hard winter wheat area of the Great Plains and the northern section of the soft winter wheat area of the Central States. As is the case in region 1, the chief source of infestation is insects in accumulations of old grain in cracks, crevices, and burrows in the woodwork of bins, and in infested millfeeds and chicken feed stored on the farm. During seasons of abundant rainfall wheat is high in moisture and particularly susceptible to attack, and damage to farm-stored grain in this region may be extensive.

Grain-storage structures of all kinds should be thoroughly cleaned, accumulations of old grain removed, and woodwork sprayed before new grain is stored. Monthly inspections of stored grain should be made after harvest until the advent of cold weather. Subsequent inspections at monthly intervals during the warm weather of the following year should also be made to determine the presence of insect infestations. Grain found to be seriously infested should be fumigated without delay.

GRAIN STORAGE IN REGION 3

Region 3 (fig. 19) comprises the central section of the soft red winter wheat area of the Eastern States, the southern portion of the Central States, and the white wheat area of California. The susceptibility of wheat to field infestations of the Angoumois grain moth in the Eastern States makes it necessary there to thresh the grain as soon after harvest as the wheat is dry, to insure it against possible severe damage. In the entire region wheat is also highly susceptible to the attack of other insect pests of stored grain; hence it is necessary to fumigate all wheat as soon as it shows signs of serious infestation.

In this region cleaning out the bins before the storage of new grain is essential. The use of a good contact spray, as described on page 18, that will penetrate cracks and burrows but will not contaminate or impart an odor to the new crop of grain is also recommended. Except during the winter, inspection of stored grain should be made monthly throughout the year. Corn grown in this region is usually stored in slat cribs that cannot be fumigated. The Angoumois grain moth frequently infests corn so stored, but little serious damage is done unless the corn is held over the summer following harvest. If storage for more than one season is contemplated, the corn should be shelled after it has become thoroughly air-dry, and before the warm summer weather of the succeeding season allows insects surviving the winter to increase to serious proportions. The shelled corn should be screened and well cleaned to remove broken kernels, insects, and other foreign material, and stored in tight bins. If serious infestation is evident in the shelled corn, it should be fumigated.

GRAIN STORAGE IN REGION 4

Region 4 (fig. 19) includes areas in the South and Southeast in which farm storage is extremely hazardous except for short periods. In this region infestation begins in the field and is frequently extensive before grain can be harvested and placed in storage. The warm, humid climate favors rapid multiplication of stored-grain insects, and the chances of sound grain becoming reinfested from outside sources are greater here than elsewhere.

Thoroughly cleaning the bins prior to storage of new grain is highly important, since accumulations of old grain in this region are invariably infested. If grain is stored, it should be fumigated immediately and monthly inspections made thereafter to determine the presence of infestations. Additional fumigation should be conducted whenever such infestations are discovered.

PREVENTIVE MEASURES BEGUN ON THE FARM

In the foregoing pages it has been pointed out that infestation in stored grain in many cases originates on the farm, either as a result of field infestation, or poor storage conditions, or both. The farm, therefore, is the logical place at which to take up preventive measures.

In sections of the country where the Angoumois grain moth is destructive, and in the South where field infestation by other insects is habitual, early harvest and early threshing in the case of small grains are essential. The Angoumois grain moth is unable to penetrate any distance below the surface of binned wheat, hence early harvesting

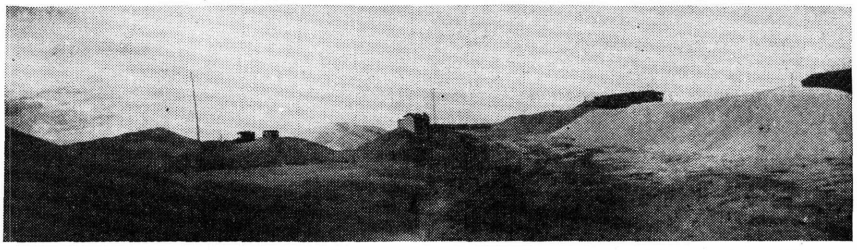


FIGURE 20.—Thousands of bushels of grain piled on ground in western Kansas awaiting transfer to storage.

and threshing will effectively prevent serious damage by this insect to wheat.

In the case of corn, where field infestation occurs, further damage can be largely prevented by shelling it as soon as the moisture content is low enough to permit. In the commercial corn area it is safe to store the corn on the ear until the arrival of warm weather the following spring or summer.

In many parts of the country facilities for the storage of grain are entirely inadequate. Conditions such as are illustrated in figure 18, where wheat is merely dumped on the floor in any convenient corner of the barn, are all too frequent. Grain so stored is open to attack by insects and rodents that abound in such situations, and heavy losses are inevitable.

In years of high production and when transportation facilities are insufficient to care for the surplus crop it is sometimes stored temporarily in any structure that will afford protection from the weather, but storage for any extended period should be in structures adapted for protecting it from insect attack.

In the Great Plains region, for lack of storage space, grain is sometimes piled on the ground as shown in figure 20. Under the semiarid conditions that prevail after harvest in this region, grain can be stored for short periods in this manner without great danger. Similar conditions occur in portions of the Pacific Northwest where bagged grain is often stored in the open along the railroads until it can be

hauled away. In general, however, small grains should be stored in bins tight enough for effective fumigation, and located far enough away from barns or other buildings to prevent infestation from such sources and to provide for the use, if necessary, of inflammable fumigants without endangering the main farm buildings.

In the South, where field infestation of corn is a serious factor, storage structures for this crop should be adapted for fumigation. In the main corn belt, however, storage in slat cribs can be utilized with safety for the first season.

The type of construction for farm storage of grain will doubtless vary with the region and the type of farming practiced. A detailed discussion of storage structures suitable for the farm storage of grain will be found in Agricultural Adjustment Administration bulletins Wheat Storage in the Ever-Normal Granary, and Corn Storage in the Ever-Normal Granary, which may be obtained from the United States Department of Agriculture.

CARE AND PREPARATION OF FARM STRUCTURES FOR GRAIN STORAGE

Before newly harvested grain is placed in storage, it is extremely important to see that the bins or granaries are clean and free from accumulations of old grain or feed that may harbor insects. Some time before harvest any small lots of grain on hand from the previous season should be fed, fumigated, or disposed of. The granaries should be thoroughly swept out, any breaks repaired, and pockets or dead spaces around the bin cleaned out, filled up, or sealed.

With wooden bins the use of a contact spray will be found useful. Care should be taken to use a spray that will not leave any odor or otherwise contaminate the grain. A satisfactory spray can be made of any good, odorless, tasteless kerosene-type oil mixed with pyrethrum extract in the proportions of 1 gallon of the extract to 19 gallons of the oil. A less expensive spray recommended by Farrar and others [1] consists of the following ingredients:

Dormant-tree spray oil	gallon 1
Lye	ounces 3
Water	gallons 9

A gallon of this spray will cover about 50 square feet of bin surface.

In the use of these sprays it must be remembered that they are about as inflammable and poisonous as kerosene and should be handled with the same care to prevent fires.

AVOIDING STORAGE OF HIGH-MOISTURE GRAIN

The moisture content of stored grain is one of the most important factors affecting its susceptibility to insect attack. The insects that breed in stored grain are dependent on their food supply for the moisture required to carry on their life processes in a normal manner. It the moisture content of grain is high, it is favorable to a rapid increase in the numbers of insects breeding in it. If, on the other hand, the moisture content of the grain is low, the water required for carrying on the vital life processes can be obtained only by breaking down

[1] FARRAR, M. D., WINBURN, T. F., and FLINT, W. P., HOW TO KNOW AND CONTROL STORED-GRAIN INSECTS, Ill. Agr. Expt. Sta. Cir. 512, 16 pp. illus. 1941.

the food reserves of the body. Loss of weight results from this consumption of the reserve body tissues, and the insects eventually die. The water requirements naturally differ with each species of insect, and some are able to subsist on drier grain than others.

The common insect pests of stored grain do not appear to breed in grain that has a moisture content of 9 percent or lower, and adults of the true grain weevils soon die in such grain. Some of the adult "bran bugs" survive for considerable periods in dry wheat but they are unable to multiply. Information on the exact moisture requirements of these insects is not complete, but it is known that the higher the mositure content of the grain the more rapid their development. Many of them appear to thrive best when grain is so damp that it begins to mold. It is extremely important, therefore, that grain be stored in as dry a condition as possible.

IMPORTANCE OF STORING CLEAN GRAIN

Grain that is to be placed in storage should be as free as possible from broken kernels and foreign material. Many kinds of "bran bugs" and lesser grain pests cannot survive in whole, sound grain that is in good condition. They breed rapidly in dirty grain that is full of broken kernels and by their activities they produce heat and moisture that puts the grain in bad condition. With the approach of cold weather surface layers of binned grain cool off more rapidly than the rest of the grain, and in infested bins moisture produced by insects condenses in the cold surface layers, causing it to mold and rot.

The presence of high percentages of broken grain, foreign material, and dust in binned grain is also thought to interfere with the proper distribution of fumigants that are applied to the surface. The vapors on encountering accumulations of these materials are deflected from the course of their downward passage so that the insects directly under such spots escape the full concentration of fumigant.

MECHANICAL HANDLING OF FARM-STORED GRAIN

Ordinarily it is considered impracticable to handle small grain on the farm to improve its condition unless the grain storage is of the elevator type equipped with machinery for elevating and transferring the grain. In the Great Plains region, where the combine harvester is almost universally used, farm-stored wheat that is found to be going out of condition is sometimes run through this machine with profit. Many insects are removed, and the general condition of the grain is improved in the process. Since immature stages of the rice and granary weevils are not free living, but are inside the kernels, they are not removed by cleaning. Small quantities of grain can be cleaned by use of a fanning mill.

USE OF DUSTS TO PROTECT GRAIN

The mixing of finely ground inert dusts, such as sand, clay, wood ashes, etc., with grain to protect it from insect attack has been advocated from time to time, but, aside from the impracticability of mixing large quantities of inert dusts with grain and removing it afterward, it has been found that none of them can be depended on to give adequate protection to grain under actual storage conditions. De-

velopment of insects in grain with which dusts are mixed is somewhat retarded, but if the moisture content of the grain is favorable for insect development, serious damage will not be prevented by the use of inert dusts.

In addition to inert dusts, a number of chemical dusts have been tried at one time or another for protecting stored grain from insect attack. These include camphor, naphthalene, paradichlorobenzene, salt, lime, sulfur, magnesium oxide, borax, copper carbonate, copper sulfate, sodium fluosilicate, barium fluosilicate, and various compounds of mercury or arsenic. **Some of these chemicals are violent poisons and must therefore be handled with care.** There is little doubt that many of the poisonous dusts are highly effective. They can be used, however, only in protecting grain that is intended for seeding purposes, and it is doubtful whether they should even be recommended for this purpose, owing to the chance that treated seed may accidentally be used for food by man or animals. Naphthalene and paradichlorobenzene act as fumigants and are sometimes used to protect seed samples or seed to be used for planting purposes. Seed so treated, if later fed to animals, has been found to taint the meat and in the case of poultry to impart an obnoxious flavor to the eggs as well. Furthermore, the vapors of paradichlorobenzene may affect the germination of the seed.

FUMIGATION FOR FARM-STORED GRAIN

Farm-stored grain that has become seriously infested should be fumigated as soon as practicable. Since under ordinary conditions grain stored on the farm cannot be readily moved from one bin to another, the fumigants that can be used successfully are limited to those that can be applied to the surface of the grain—the so-called heavier-than-air fumigants. The chemicals in common use for this purpose are the ethylene dichloride-carbon tetrachloride mixture, carbon disulfide, and mixtures of carbon disulfide with carbon tetrachloride and other flame-depressing agents. These fumigants may be sold as such or under different trade names.

The fumigation of farm-stored grain can ordinarily be accomplished in a satisfactory manner with simple equipment and with a minimum of effort. There are, however, a number of factors that affect the efficiency of any fumigation which must be taken into consideration if successful results are to be obtained.

In order to obtain the best results in the fumigation of farm-stored grain it is necessary to have a tightly constructed bin. The average farm bin is not gas tight, but is designed chiefly to confine the grain and protect it from the weather. Usually a maximum dosage must be used in order to compensate for the natural leakage of the gas. If bins are entirely gas tight minimum dosages can be used successfully.

The surface area of a bin in relation to the depth of the grain must be considered in planning the dosage. If the surface area of the grain is relatively small, a uniform coverage of the surface can be obtained with a relatively small quantity of fumigant. Furthermore, the loss of fumigant from surface evaporation is in direct proportion to surface area. If the surface area is large, and the bin is shallow, heavier dosages of fumigant are required than if the bin were deep and had a small surface area.

Bins that are too full are difficult to fumigate, since the vapors of liquid fumigants applied to the surface have a tendency to roll over the edges of the bin and be lost. The surface of the grain should be level and at least 6 inches below the top of the side walls of the bin. The vapors of the fumigant will then diffuse downward through the grain instead of escaping over the top of the bin.

Caking of the surface grain, due to the webbing of insects or the condensation of moisture, may prevent the uniform penetration of the grain by the vapors of the fumigant. If there is any indication of caking, the surface layer should be broken up by raking to a depth of several inches.

It has been found that the uniform application of a liquid fumigant to the entire surface of a bin of grain will give the most efficient results. The vapors of such fumigants appear to channel down through a mass of grain in a vertical direction from the immediate point of application with relatively little lateral diffusion. Uniform application is therefore essential.

Temperature and air movement are also factors of great importance. Insects are more active and more susceptible to the effect of fumigants when the weather is warm than when it is cold, and to a certain extent fumigants diffuse better and are more effective under such conditions. At the same time it must be realized that fumigants vaporize more rapidly at higher temperatures and that the loss from surface evaporation when they are applied during periods of high temperature may more than offset the greater effectiveness at such temperatures. It has been found that at grain temperatures of from 65° to 75° F. excellent results can be obtained, with a minimum loss of fumigant through evaporation. When fumigation is required during periods of warm weather, it is advisable to treat bins during the early morning hours while the air above the grain is comparatively cool. High winds greatly increase the loss of fumigants resulting from surface evaporation and further decrease the efficiency of a fumigation by causing a drift of the fumigant to one side of a bin. Whenever possible bins should be fumigated when there is little air movement.

ETHYLENE DICHLORIDE-CARBON TETRACHLORIDE MIXTURE

A mixture of 3 parts by volume of ethylene dichloride with 1 part of carbon tetrachloride has been found well adapted for the treatment of farm-stored grain, and its use is recommended wherever possible.

Ethylene dichloride is a colorless liquid with an odor similar to that of chloroform. On exposure to air it evaporates slowly, forming a vapor that is slightly heavier than air. When applied to the surface of a bin of grain the vapors diffuse downward through the grain to the bottom. No adverse effect upon the germination of the grain is noticeable regardless of the concentration, the length of exposure, or the moisture content of the grain.

Since the vapors of ethylene dichloride are inflammable, it is customary to use this fumigant in combination with carbon tetrachloride. A mixture of 3 parts by volume of ethylene dichloride with 1 part of carbon tetrachloride is free from fire hazard under ordinary conditions. This mixture is ordinarily sold under various trade names and should be purchased ready-mixed from the dealer or manufacturer.

In applying the mixture to a bin of grain, the fumigator should avoid inhaling any of the vapors, even those from light concentrations,

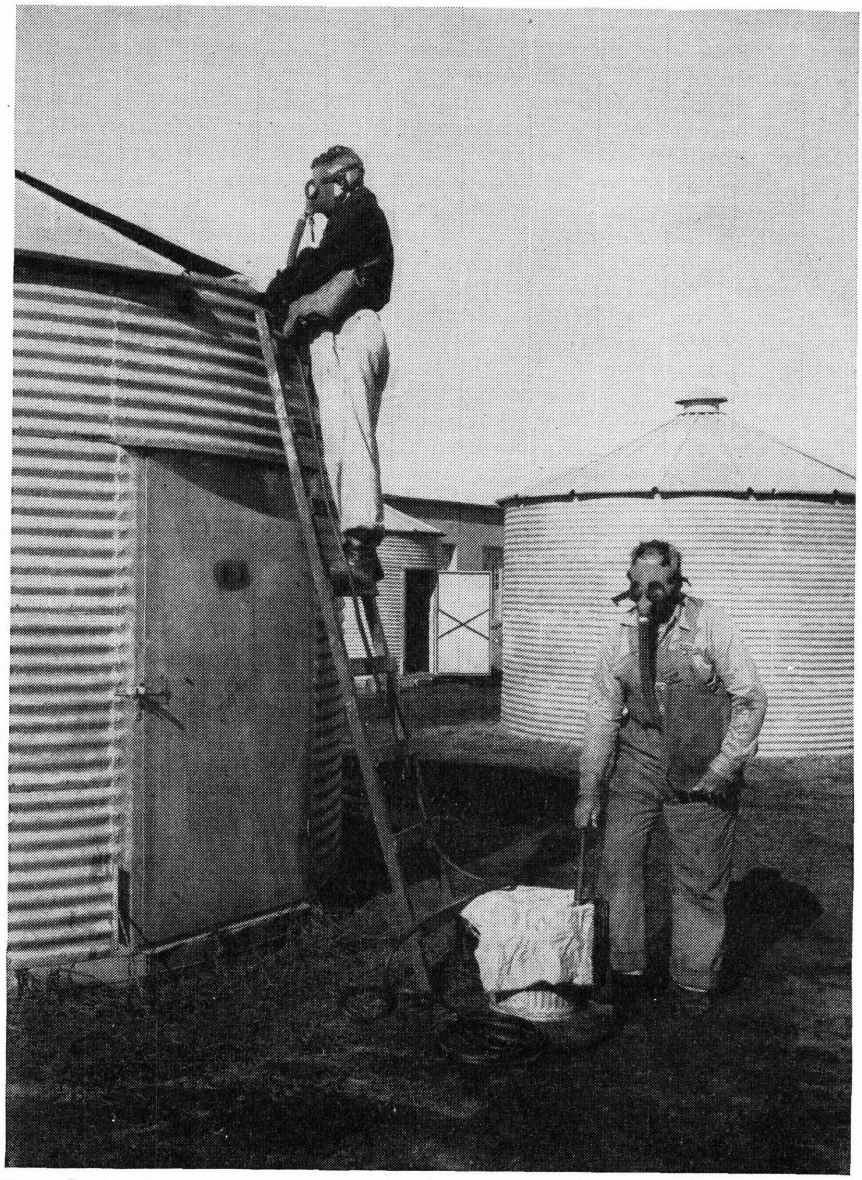


FIGURE 21.—Applying the ethylene dichloride-carbon tetrachloride mixture with a hand-operated sprayer. A uniform distribution of the fumigant over the surface of the grain can be obtained in this way without exposing the operator to strong concentrations of the gas. The operator should, however, wear a gas mask for protection from the vapors.

and also avoid spilling this or any mixture containing carbon tetrachloride on the clothing or hands. The most satisfactory method is to apply the fumigant from the outside of the bin, as shown in figure 21.

An inexpensive bucket sprayer or a larger power sprayer is used to spray the liquid uniformly over the surface of the grain.

It is unwise to attempt to apply the fumigant with a sprinkling can, since the vapors have an anaesthetic action when breathed in concentrated form, and fumigators exposed to the vapors for any appreciable period are likely to be made seriously ill. A gas mask provided with a full face piece and a black canister approved by the United States Bureau of Mines for protection against these gases should always be worn by anyone who is exposed to the concentrated vapors for more than a very brief period.

A dosage of 6 gallons of the mixture per 1,000 bushels of grain is the recommended dosage in tight, well-constructed bins. If, however, the bin is shallow and has a large surface area, it may be necessary to increase the dosage to 8 gallons per 1,000 bushels.

A more toxic fumigant has recently come into use. This is made by adding 10 percent by volume of methyl bromide to the 3-to-1 mixture of ethylene dichloride and carbon tetrachloride. A 2-gallon dose of this mixture has been found equivalent to the 6-gallon dose of the old mixture. **This mixture is very poisonous and should be prepared only by a qualified manufacturer, and the operator should remain outside the bin and apply it with a sprayer. It must not be handled or applied without the use of a gas mask with a full face piece and a black canister of the type approved by the United States Bureau of Mines for protection against organic vapors. The canister should be replaced by a fresh one at intervals frequent enough to insure complete protection from the vapors.** So little information is available as to the concentrations present at any time during the fumigation at the place where the operator stands, that it is recommended that the use of a canister be limited to 1 hour unless it is definitely determined by tests made by experienced research workers that the canister can be used for longer periods with safety. If the bin is in a building, precautions should be taken to see that no persons or animals are allowed in the building until after 72 hours have elapsed after the fumigation.

MIXTURES OF CARBON DISULFIDE AND OTHER CHEMICALS

Carbon disulfide has long been a popular fumigant for the treatment of farm-stored grain. It is dangerous to use, however, owing to the highly inflammable and explosive nature of its vapors when mixed with air. Furthermore, fire insurance is likely to be voided while carbon disulfide is being used. For these reasons the use of carbon disulfide alone is not recommended for the fumigation of farm-stored grain.

Mixtures of carbon disulfide and other chemicals such as carbon tetrachloride and sulfur dioxide, made for the purpose of reducing the fire hazard, are now available commercially at a price of about $2 per gallon f. o. b. factory. These mixtures consist of approximately 20 percent of carbon disulfide and 80 percent of carbon tetrachloride, to which may be added a small quantity of sulfur dioxide or other chemicals. When properly made such mixtures appear to be relatively free from fire hazard. It is not advisable for the layman to attempt the manufacture of such mixtures, since the safety of the fumigant from fire hazard is dependent upon its proper preparation. Only such mixtures as are sanctioned by fire insurance underwriters should

be used. The vapors of carbon disulfide are poisonous to human beings if breathed for any length of time. Exposure to light concentrations may induce a feeling of giddiness, which, however, will quickly pass off when one comes out into the fresh air. The toxicity of carbon tetrachloride to man is about equivalent to that of carbon disulfide.

It is recommended that these mixtures be applied in the same manner and at the same dosages recommended for the ethylene dichloride-carbon tetrachloride mixture.

OILING THE SURFACE LAYER OF SHELLED CORN TO PREVENT REINFESTATION

Shelled corn stored in metal bins oftentimes becomes reinfested shortly after fumigation, through the reentry of insects that were driven out by the fumigation or the entry of insects that have flown or crawled from nearby sources of infestation. It has been found by Farrar and others that such reinfestations can be reduced greatly by spraying the top surface of the grain with a light application of oil, using 2 quarts for each 1,000 bushels of corn. The oil should be either technical white or other refined oil of 100 to 200 seconds viscosity (Saybolt 100° F.) and be free from objectionable odors. In order to avoid possible reduction in grade of the grain, care must be taken not to use too much oil or one having a strong odor. Kerosene or waste oil should not be used. The oil can be applied separately or in the last 2 gallons or so of fumigant and forms a protective coating over a shallow surface layer of the grain.

U. S. GOVERNMENT PRINTING OFFICE: 1942

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents